

# INTRODUCTION TO NEUTRON SCATTERING

Boualem Hammouda

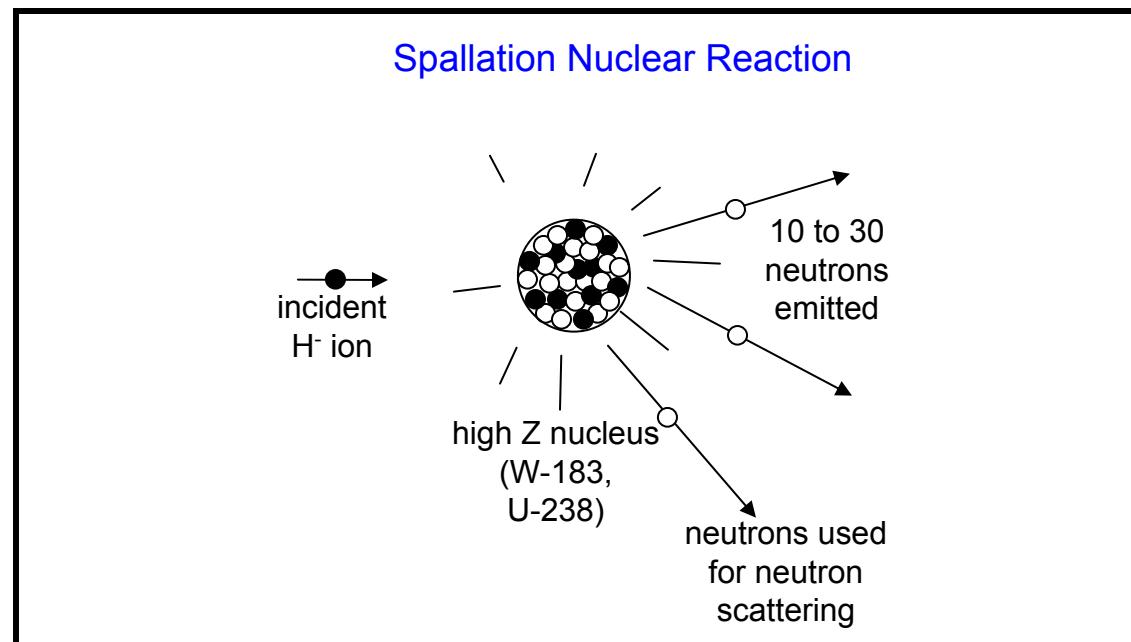
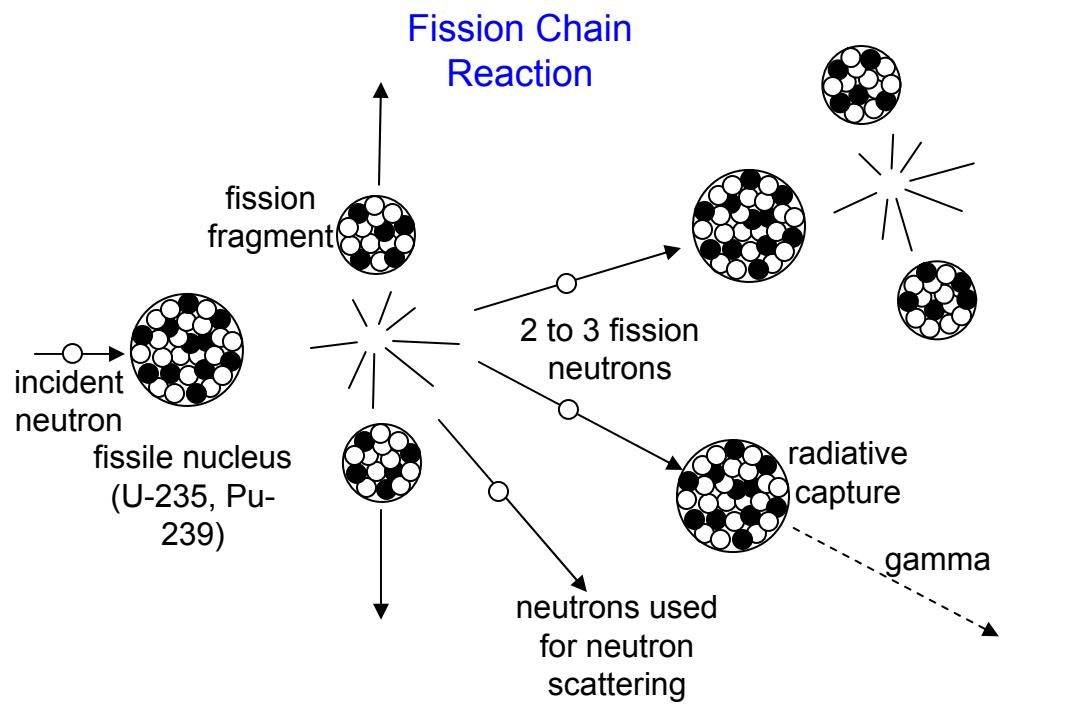
National Institute of Standards and Technology  
Center for Neutron Research

- Why Use Neutrons?
- **Neutron Sources**
- Continuous vs Time-of-Flight
- Neutron Sources in the US
- The **NIST** Neutron Scattering Facilities
- Neutron interactions
- Elastic vs Inelastic Scattering
- Coherent and Incoherent Scattering
- Neutron **Scattering Lengths** and **Contrast Factors**
- Introduction to SANS

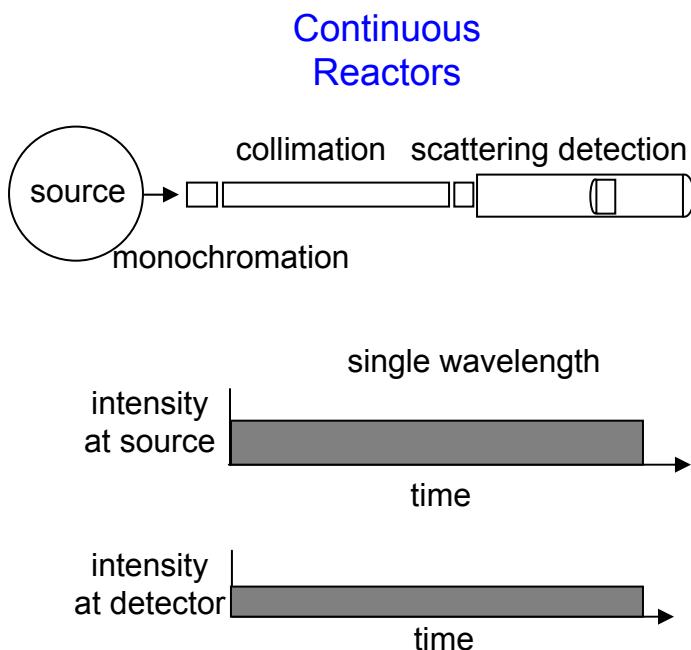
# WHY USE NEUTRONS?

- Neutrons interact through short-range nuclear interactions. They have no charge and are **very** penetrating and **do not destroy samples**.
- **Neutron wavelengths** are comparable to **atomic sizes** and interdistance spacings.
- Neutrons interactions with **hydrogen** and deuterium are widely different making the **deuterium labeling method** an advantage.

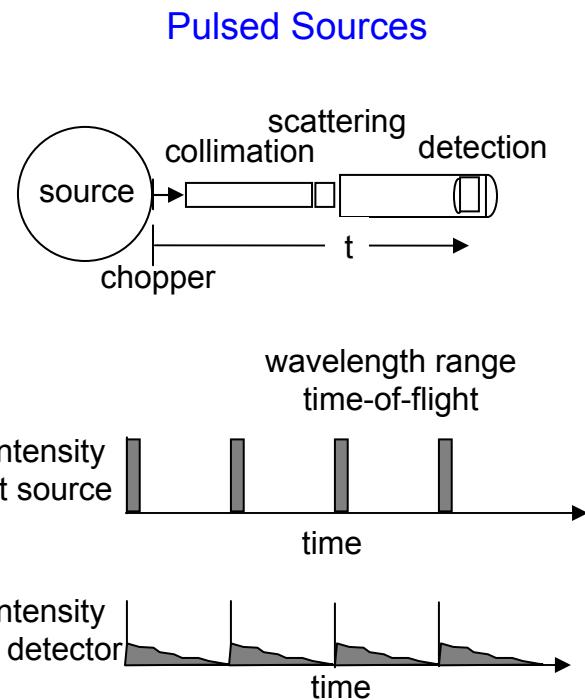
# NEUTRON SOURCES



# CONTINUOUS VS TIME-OF-FLIGHT



Measure some of the neutrons all of the time



Measure all of the neutrons some of the time

# NEUTRON SOURCES IN THE US

## Continuous Sources:

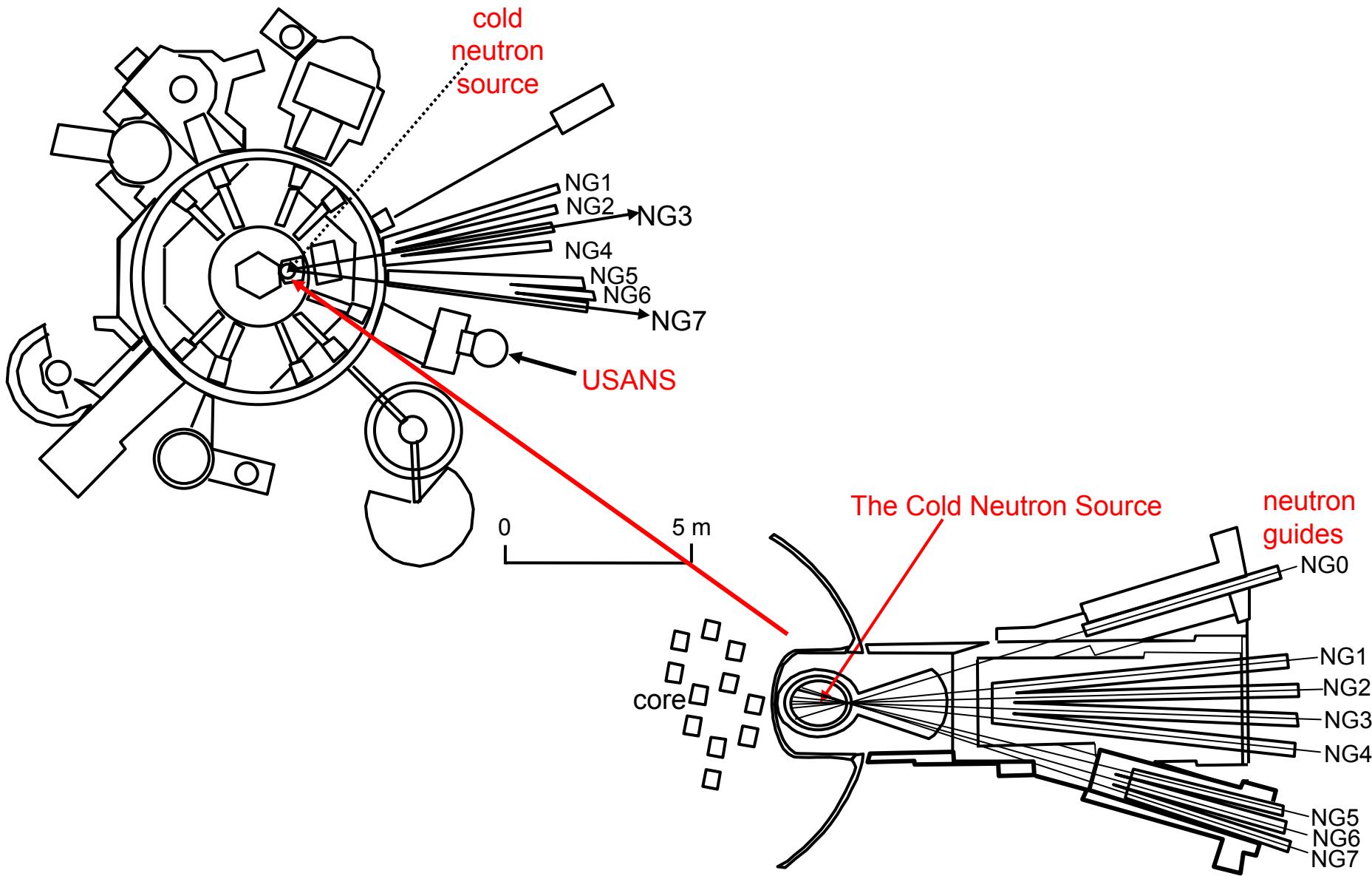
- HFIR-**Oak Ridge** National Laboratory. <http://neutrons.ornl.gov>.
- NIST-**National Institute of Standards and Technology**. <http://www.ncnr.nist.gov>.

## Pulsed Sources:

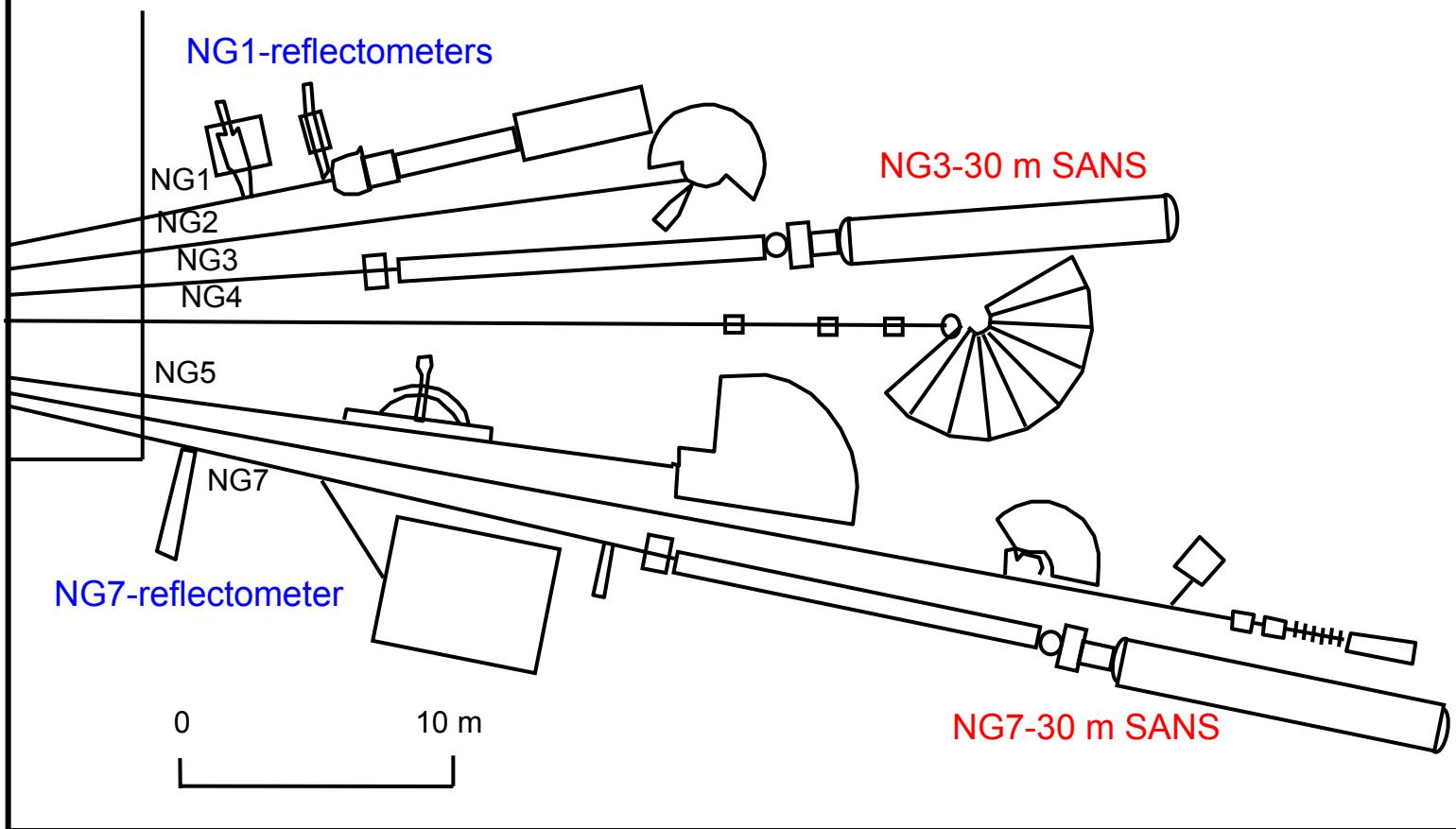
- IPNS (**Argonne** National Lab). <http://www.pns.anl.gov>.
- WNR/PSR LANSCE (**Los Alamos**). <http://lansce.lanl.gov>
- **SNS** (Oak Ridge National Lab). <http://www.sns.gov>.

NIST Thermal Instruments

# THE NIST NEUTRON SOURCE



# The NIST Guide Hall

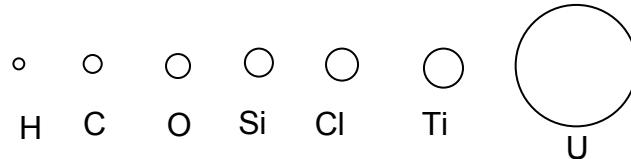


## The NIST Guide Hall



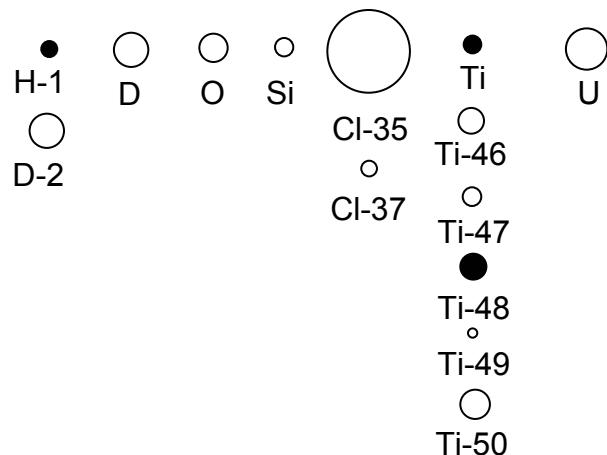
# NEUTRON INTERACTIONS

Nuclei Seen by X-Rays



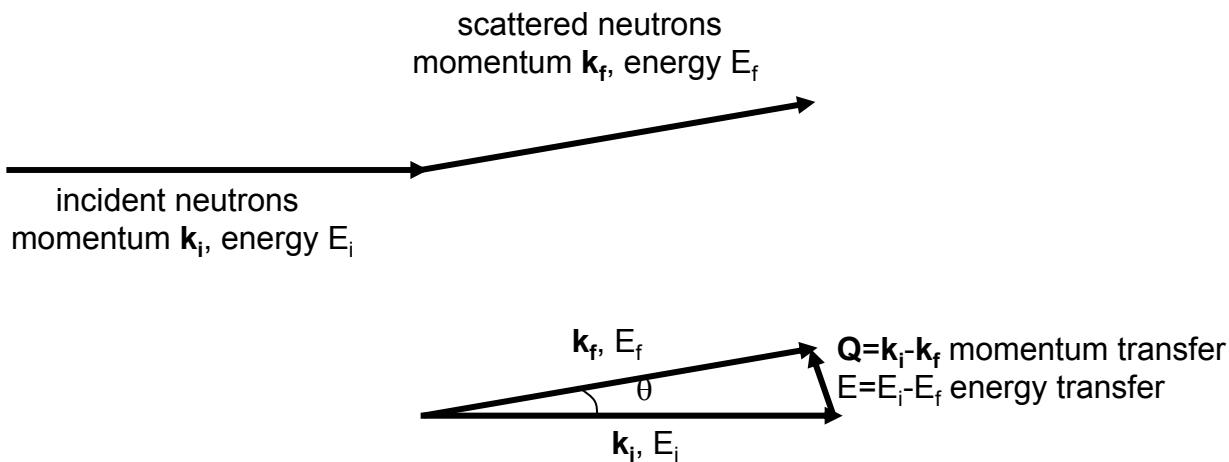
X-rays interact with the electron cloud.

Nuclei Seen by Neutrons



Neutrons interact with the nuclei.  
Negative scattering lengths in dark.

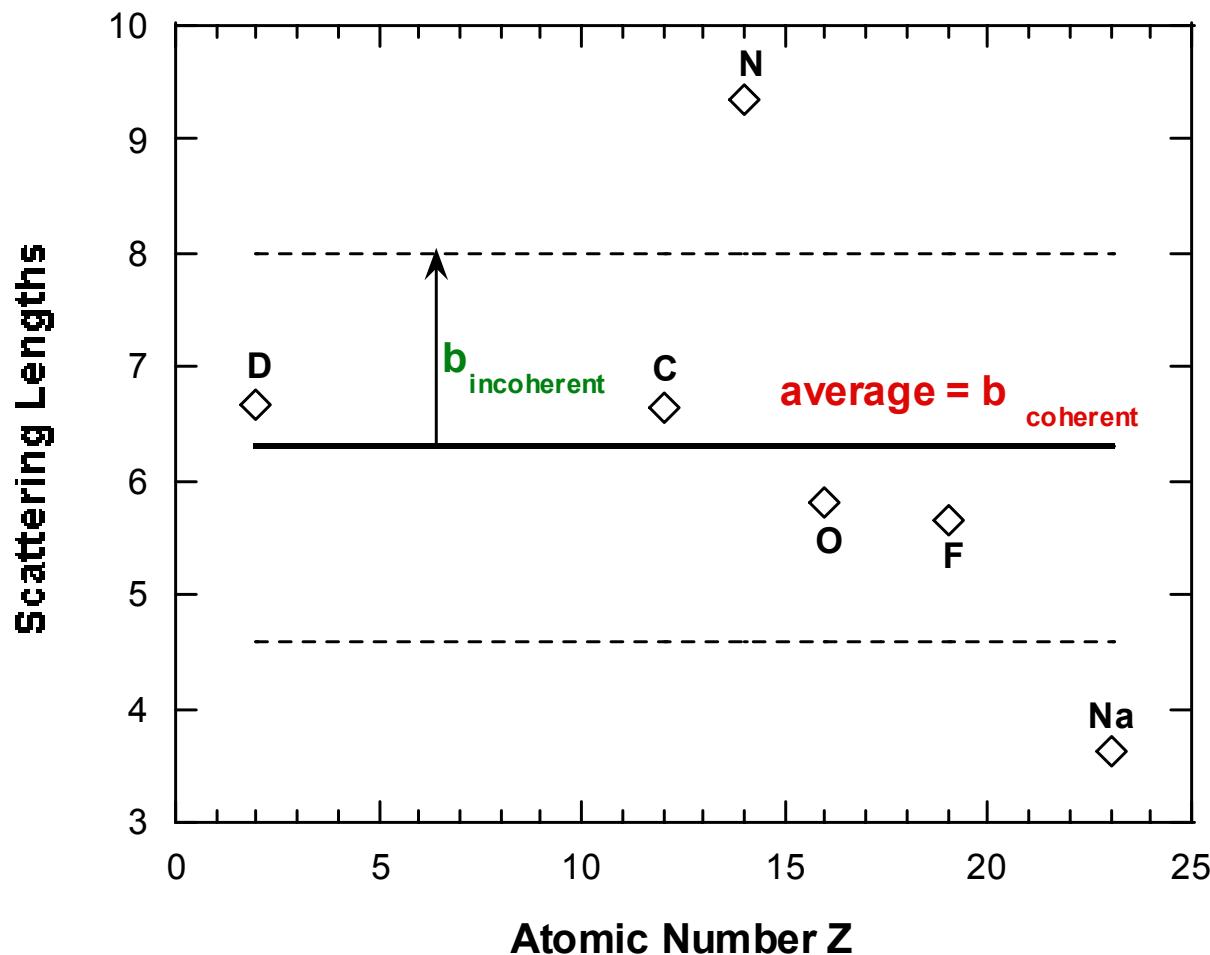
# ELASTIC vs INELASTIC NEUTRON SCATTERING



Elastic scattering corresponds to  $E=0$ . Investigate structures.

SANS and NR are elastic scattering techniques.

# COHERENT AND INCOHERENT SCATTERING



# NEUTRON SCATTERING LENGTHS AND CROSS SECTIONS

	Scattering Lengths		Scattering Cross Sections		
	Coherent	Incoherent	Coherent	Incoherent	Absorption
Element	$b_c$ Fermi	$b_i$ Fermi	$\sigma_c$ Barn	$\sigma_i$ Barn	$\sigma_a$ Barn
H-1	-3.739	25.278	1.757	80.30	0.333
D-2	6.671	4.04	5.592	2.05	0.000
C-12	6.646	0	5.550	0.001	0.003
N-14	9.36	2.0	11.01	0.50	1.90
O-16	5.803	0	4.232	0.000	0.000
F-19	5.654	0	4.232	0.001	0.000
Na-23	3.63	3.59	1.66	1.62	0.530

1 Fermi =  $10^{-13}$  cm.

1 Barn =  $10^{-24}$  cm<sup>2</sup>.

### **Case of D<sub>2</sub>O:**

Mass m<sub>D<sub>2</sub>O</sub> = 20 g/mole, Density d<sub>D<sub>2</sub>O</sub> = 1.111 g/cm<sup>3</sup>.

Specific Volume = v<sub>D<sub>2</sub>O</sub> = m<sub>D<sub>2</sub>O</sub>/d<sub>D<sub>2</sub>O</sub> = 18 cm<sup>3</sup>/mole.

Scattering Length: b<sub>D<sub>2</sub>O</sub> = 2b<sub>D</sub>+b<sub>O</sub> = (2\*6.671+5.803) \*10<sup>-13</sup> = 19.145\*10<sup>-13</sup> cm.

Scattering Length Density: b<sub>D<sub>2</sub>O</sub>/v<sub>D<sub>2</sub>O</sub> = 1.064\*10<sup>-13</sup> cm<sup>-2</sup>mole = 6.38\*10<sup>-6</sup> Å<sup>-2</sup>.

Microscopic coherent scattering cross section σ<sub>c</sub> = 4π <b><sup>2</sup> units of barns.

Macroscopic coherent scattering cross section: Σ<sub>c</sub> =(N/V) σ<sub>c</sub> units of cm<sup>-1</sup>.

Contrast factor (mixture of A in B): (b<sub>A</sub>/v<sub>A</sub>-b<sub>B</sub>/v<sub>B</sub>)<sup>2</sup> in units of cm<sup>-4</sup>.

### **Example of Poly(ethylene oxide)/Deuterated Water (hPEO/D<sub>2</sub>O) Solution:**

hPEO: C<sub>2</sub>H<sub>4</sub>O, b<sub>hPEO</sub> = 4.139\*10<sup>-13</sup> cm, V<sub>hPEO</sub> = 38.94 cm<sup>3</sup>/mole

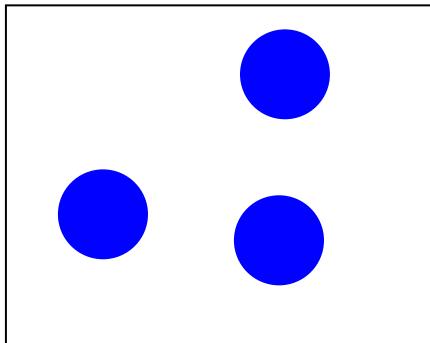
d-water: D<sub>2</sub>O, b<sub>D<sub>2</sub>O</sub> = 19.14\*10<sup>-13</sup> cm, V<sub>D<sub>2</sub>O</sub> = 18 cm<sup>3</sup>/mole

Contrast factor: (b<sub>hPEO</sub>/v<sub>hPEO</sub>-b<sub>D<sub>2</sub>O</sub>/v<sub>D<sub>2</sub>O</sub>)<sup>2</sup>N<sub>av</sub>=5.498\*10<sup>-3</sup> mole/cm<sup>4</sup>. N<sub>av</sub> is Avogadro's #.

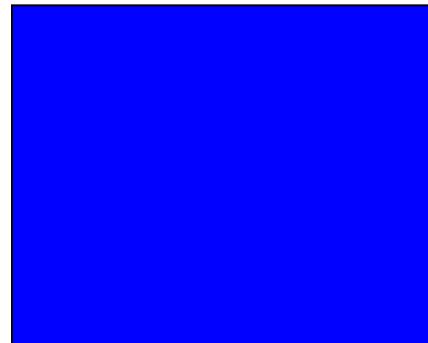
### **Online Scattering Length Density/Cross Section Calculator:**

<http://www.ncnr.nist.gov/resources/sldcalc.html>

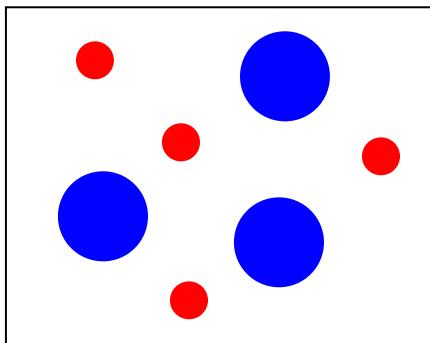
# The Contrast Match Method



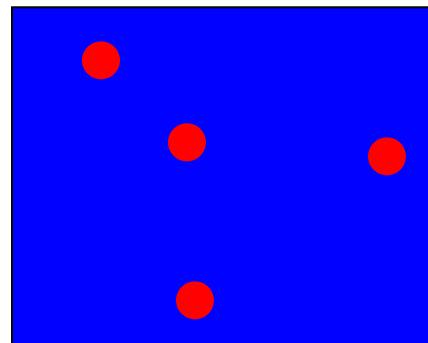
Finite contrast



Zero contrast

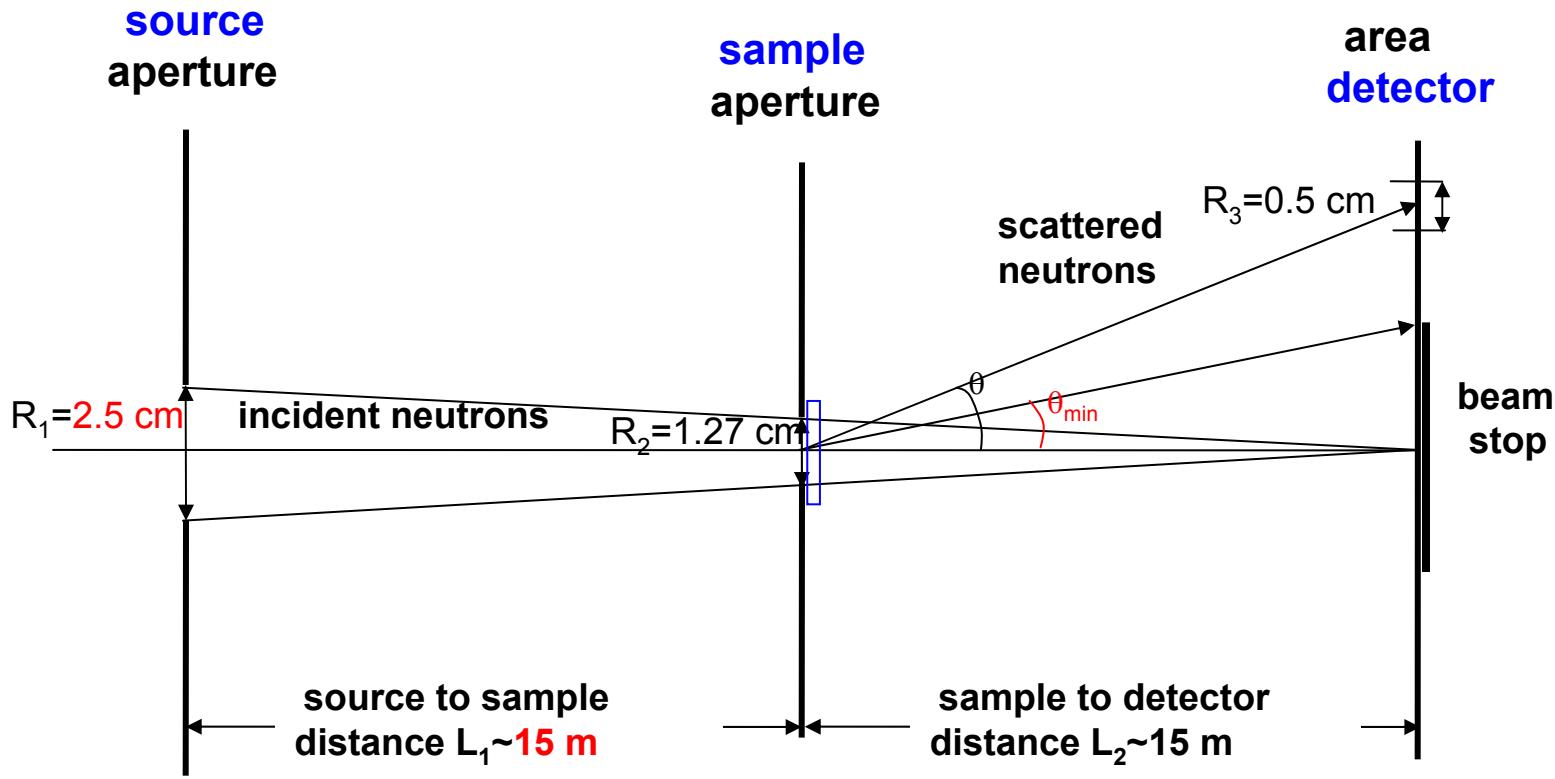


Multiple contrasts



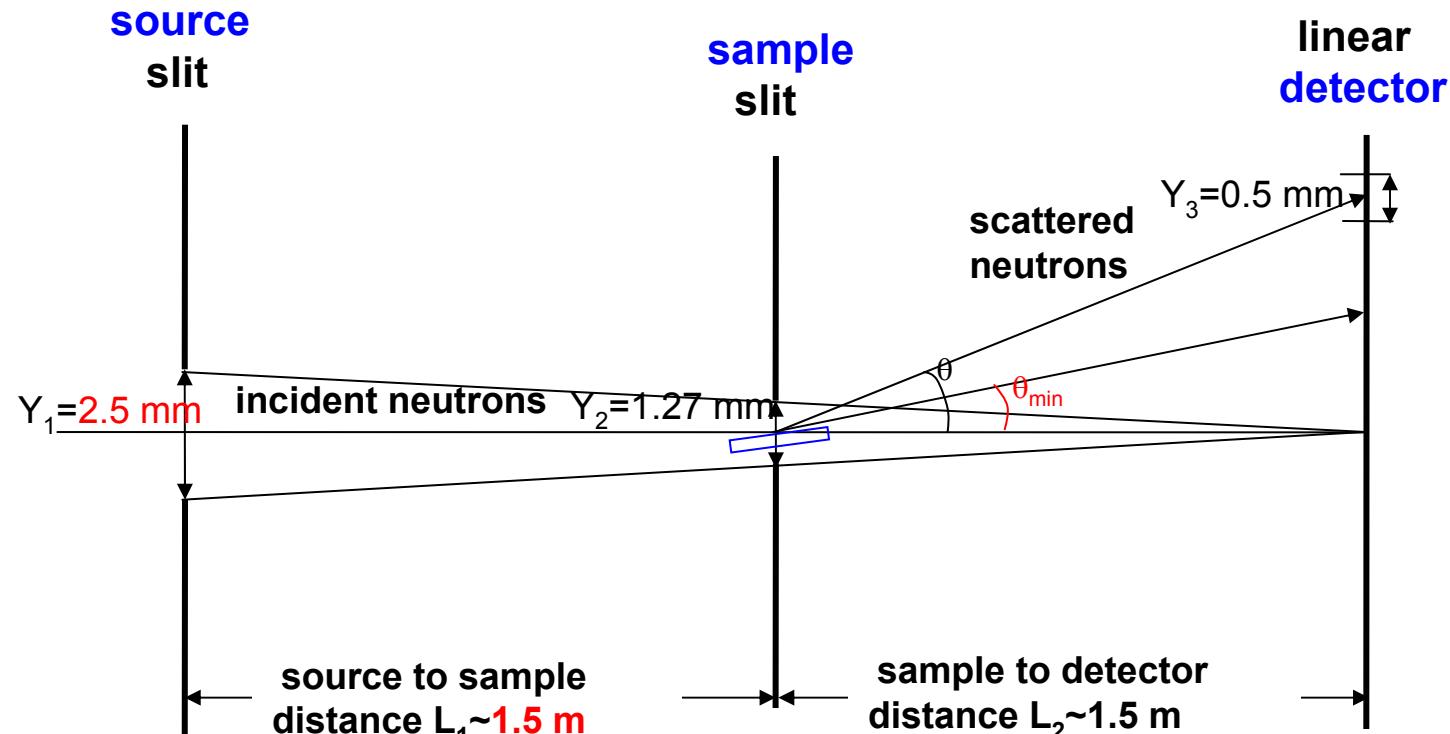
Contrast match

## SANS GEOMETRY



$$\theta_{\min} = (R_1 + R_2)/L_1 + R_2/L_2 + R_3/L_2 \sim 3.7 \times 10^{-3} \text{ Rad}$$

## REFLECTOMETRY GEOMETRY



$$\theta_{\min} = (R_1 + R_2)/L_1 + R_2/L_2 + R_3/L_2 \sim 3.7 \times 10^{-3} \text{ Rad}$$